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Analysis of energetic exploitation of straw in Vojvodina

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ABSTRACT

The Autonomous Province of Vojvodina is an autonomous province in the Republic of Serbia. It is located in the northern part of the country, in the Pannonia plain. Vojvodina is an energy-deficient province. The average yearly quantity of the cellulose wastes in Vojvodina amounts to about 9 millions tons barely in the agriculture, and the same potential on the level of Serbia estimates to almost 13 million tons. This study gives the analysis of energetic exploitation of straws from stubble cereals processed in different forms. Costs for the equipment that uses biomass in the EU are approximately two times higher with respect to those for the equipment for combustion of natural gas or of fuel oil. Costs of investments for combustion of biomass in Vojvodina if compared with the cited data are approximately for 40–50% lower. The difference of the investment costs for the construction of such units is because units for straw combustion designed and constructed in our country, have neither the complicated devices for manipulation of fuels, nor the devices for the waste gasses processing. The definite conclusions about the economic justification of the energetic exploitation of stubble straws can be obtained only by comparison of costs of the so obtained energy, with the costs of energy obtained through the combustion of classical fuels. Previous comparisons were the most often based on the comparisons of value of prices of the equivalent straw quantity with the process of fuel oil of other classical fuels. Such the comparisons leaded to the very positive evaluations of the economical effects of straws, without taking into account the realizability of the named method. Namely, comparisons of straw and fuel oil hardly could lead to the conclusion that these two fuels are mutually substitutable. According to its physical properties, straw is most similar to firewood, but the preciousness and lacking of this the very resource excludes it from the comparative analysis, so that comparisons were performed with respect to coal. The basic reason for the application of coal as the alternative energent is the circumstance that coal represents very often-used energent whose technology of combustion is the most similar to those used for straw, and at the same time, it has not any other application.

Contents

1. Introduction

The Autonomous Province of Vojvodina is an autonomous province in the Republic of Serbia, with about 27% of its total population according to the 2002 Census. It is located in the northern part of the country, in the Pannonia plain. Vojvodina is an energy-deficient province. Waste biomass, that is considered as a potential energy source, can be divided on biomass originated in the forestry and the biomass generated in the agriculture. The waste biomass, generated in the agriculture, can further be divided according to the agriculture branches on biomasses from field crops cultivation, or from orchards- and vineyards, and that from the livestock cultivation. In spite to the fact that this the very last waste represents waste directly originated by the animals, owing to the fact that it

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contains organic substances that basically are of the plant origin, it is considered to be the biomass. The field crops cultivation biomass is the largest potentionaly available biomass and it is contained in the residues obtained during the primary harvesting of the field products [1]. The average yearly obtained of the (lygno) cellulosic wastes in Vojvodina make some 9 million tons only in the agriculture, and the same potential for Serbia estimates to just something less than 13 million of tons. Only small part of straws is utilized, and about two thirds are combusted on the allotments, due to the problems connected with their plowing under [2,3].

The costs of exploitation of straw include costs for collecting of straw, costs for transportation to the storage location, costs of manipulation and storaging and costs for energetic conversion, i.e. of combustion. Compared with standard energents, it is obvious to perform the correction for price difference between the biomass combustion firebox and standard firebox, while, owing to problems emerged at combustion of biomass; those fireboxes are for some 50% more expensive. As the fact, calculations of costs of energetic exploitation should start with the evaluation of value of post-harvest residues, i.e. of straw at the harvest location. However, for calculations referred to energetic usage of straw, the value of the post-harvest residues is neglected. Calculation of costs in the conformity with the dividing of the whole process is performed with respect to the two techno-economic entities: (1) calculation of costs for collection, transportation, manipulation and storaging (these activities are interlinked and mutually interrelated), and (2) calculation of costs for combustion of straw. Separate calculations of these costs are performed because of they represent the distinctive processes, as well as because such an approach was applied for coal as an alternative energent [2]. This study analyzes energetic exploitation of straws remained from stubble grains production collected in their different forms [4–6].

2. Costs for straw collecting and preparing in the form of small rectangular bales

Preliminary preparation of straw (baling) in the form of small rectangular bales is the most often-applied technique at the farms in Vojvodina. The advantages of such one preparation compared with the preparation of straw in the forms of great round-shaped- or rectangular-shaped bales reflect themselves on the broad presence of presses for such one baling on the farms in Vojvodina. Farms in Vojvodina, owing to their relatively small capacities, are enforced to apply such a procedure for preparation of straw. The average acreage of farms in Vojvodina amounts to total area of 2.91 ha, i.e. to 2.76 ha of the aril area, which figures are among the smallest ones if compared with the EU situation. Besides, they are based on the recognized and approved solutions, which showed their efficacy in the practical applications. Significant is the circumstance that the assurance of the spare parts and of utilities for such presses is very simple, so that the overall maintenance of this kind of presses represents not a problem [2].

Summarizing of the individual categories and the established performances gives the total costs necessary for collection, transportation and manipulation of straw in the form of small rectangular bales. The costs of storaging take in account that the losses of the used straw amount to 20%. The overview of the total costs for collecting of straw in the form of small rectangular bales is given in Table 1.

3. Costs for preparation of straw in the form of large round-shaped bales

The collection of the stubble cereals straw using the system of large rolling bales represents the almost completely mechanized mode of the pretreatment of the post-harvest residues. The basic features of such one system are the increased dimensions and compactness of bales that assures obtaining of only six to seven bales per 1 ha. While at similar circumstances, using of the equipment for classical rectangular bales lifers even more than 200 bales per hectare, the simplification of the process and diminishing of the manipulation costs are obvious. In consonance with the total concept of technology of production of large bales, their collection process is also highly mechanized. This means almost total lacking of the manual work for the manipulations with this kind of straw bales. Total manipulation with the roll-shaped bales is mechanized, with the usage of the loaders attached on the tractor assembly.

The overview of total costs of preparation of the roll-shaped bales shows Table 2. Cost calculation includes all partial costs defined in the previous part of this study, and the assumed costs for storage are also based on the loss of 20% of straw during storaging. The economic evaluation of this loss was performed on the basis of costs of previous phases in the process of preparation of straw.

Table 1
Calculation of total costs for straw preparation in the form of small rectangular-shaped bales.

Costs category	Costs (€/ton)	Structure (%)
Baling	4.5	25.69
Materials	2	11.38
Lading	1.2	7.02
Transportation	5.7	32.22
Manipulation	1.2	7.02
Storaging	2.9	16.67
Total	17.6	100

Table 2
Calculation of total costs for straw preparation in the form of large roll-shaped bales.

Costs category	Costs (€/ton)	Structure (%)
Baling	4.6	28.85
Materials	0.5	3.39
Lading and transportation	5.6	35.25
Manipulation	1.1	6.60
Unrolling	1.5	9.25
Storaging	2.7	16.67
Total	16	100

4. Costs of combustion of straw

When talking about the costs of biomass combustion, it is substantially to emphasize that the calorific value represents one of the basic parameters determining applicability of use of a material as a fuel. Table 3 shows lower heating values of biofuels at their storage moisture contents (wheat straw 14%, corn stalk 16%, soy straw and rape straw 12%). From the given data, it can be seen that these values (lower calorific value) are similar to those for lignite from domestic coal mines that are to some degree lower if compared with the above mentioned data on the minimal moisture content of straw.

Table 3
Lower calorific values of distinctive kinds of the post-harvest residues.

Biomass	Lower calorific value (MJ/kg)
Wheat straw	14.00
Barley straw	14.20
Oats straw	14.50
Rye straw	14.00
Soybean straw	15.70
Rapes straw	17.40
Cornstalks	13.50

Table 4
Total investment costs for bioenergetic plants compared with costs for oil- and gas fueled plants.

Category of the boiler	Total investment costs (000 €)	Investments for the equipment (%)	Investments for buildings (%)	Investments for electro- and light metal equipment (%)	Overheads (%)	Total cost for the equivalent plant with fuel oil- or gas fueling (000 €)
Boiler 500 kW	125–250	70–80	15–20	2–3	10–15	90–110
Boiler 1 MW with the production building	250–400	55–65	20–30	3–6	10–15	100–150
Heating plant 5 MW	1250–1500	50–60	20–30	5–10	10–15	550–750
Steam boiler 10 MW – heating plant with building	5500–7000	50–55	30–35	3–6	10–15	1500–2000
Heating plant 14 MW	8500–11000	55–65	20–30	5–10	10–15	3500–7500

The dominant component of a biomass is cellulose (more than 50%), which is followed with pentosans, furfural. In addition, other components present in less prominent quantities. Calorific value of biomass finds somewhere in the ranges of 15–18 MJ/kg, while the elementary composition of biomass, calculated to the dry substance, is similar with that of the wood. Problematics of the combustion of biomass is very wide field for investigations and it is determined with kind and assortment of biomass, its anulometric composition and form (loose, baled, briquetted and pelleted), moisture content, kind of plant used for combustion and other factors.

The feature, which is of the crucial importance for analyzing of the combustion costs of the post-harvest residues, i.e. of straw, is the capacity of the unit for combustion. In the various references, most often the data, concerning plants with higher powers and higher automatization levels can be found [2]. These data refer to the firing units that serve as thermal energy sources for the whole plants or even for the residential settlements. By this mode of activities, very large population of small individual users that could use straw originated at their own properties is neglected. Such cases refer, most often, to the hand-operated furnaces adapted for the condominium heating of the smaller objects. Such one fire places are not basically different from fire places that are normally used in the households, either with respect to their price, or with respect to the exploitation mode, so that the more prominent differences in the application costs do not appear.

It is well known that the price of energy obtained from biomass largely depends on its investment price of the plant used for the production of energy. One of the most often technologies for energetic usage of biomass is its combustion. Because of that for the combustion of biomass, i.e. of biofuels, specific boiler facilities, adapted to the composition and granulation of fuels, prepared in special machines and facilities, were designed, aiming to the best possible combustion. Basic specifications of the plants for pretreatment and combustion of larger quantities of biomass, in comparison to the classical firing plants, are as follows: biomass combustion is performed in the wholly pretreated firebox; biomass has to be preliminary ground, comminuted, or compressed in the granular form; fire boxes are equipped with the automatized devices for their accurate controlling. The quantity of fuel interjected in fire box must be harmonized with the consumption of thermal energy. Inputs of primary and secondary air are adjusted, depending on fuel quantity and its moisture content. These claims are fulfilled by the incorporation of special devices for the automatized control. For steam boiler firing, as the fuel can be used granules obtained by pressing of biomass, as well. The introduction of the granules is performed with spiral conveyer, whose rate is regulated with automatic devices. All abovementioned methods refer to the standard boiler plant for combustion of already comminuted straw of stubble cereals. These plants are indeed more complicated than the systems that were analyzed on the terrain and they, by the rule, include screw conveyer, ventilator, the boiler, turbulent fire box, cyclone, chimney, opening for cleaning and silos recipient for straw.

Just discussed quotations refer to the high capacity firing units, but the first analyzed firing place was composed from four boiler combination of the nominal power of 100 kW and uses small rectangular bales as a fuel. The second discussed unit for performing the calculation of costs, with total power being 1.2 MW, is composed of three boilers having individual capacities of 400 kW, and it was adapted for all sorts of baled straw.

The boilers for combustion of straw were, by the rule, of small installed power and with relatively low degrees of utilization of energy. Now, in the developed countries, the small boilers for heating of households reached very high degree of the usefulness (more than 85%) and have very low degrees of emissions of the uncombusted gasses (less than 100 ppm CO). Prices of small boiler plants for biomass combustion show very wide diapason, depending on the kind of fuel, mode of dosing of fuel, and degree of automatization of the boiler operations.

Generally, boilers with lower powers have higher specific prices, but crucial influence on price has the automatization degree. In addition, the effects of the fuel nature on boiler price should not be neglected. For example, boilers used for combustion of straw are, by the rule, for 10–50% more expensive, than the boilers with similar power, aimed for combustion of the biomass characterized by woody nature.

For systems with power of firebox of more than 5 kW, expensive systems for dust collection have to be applied. Most often, the electro-filters with sack inserts are used, instead of multi cyclones or with the additional usage of multi cyclones. Besides to that, for higher powers boilers are used for steam production as well (for supply with thermal energy that is necessary for technological processes), leading to increased expenditures in comparison with plants used only for hot water production. Here the following rules-of-thumb apply: if one wishes to use boiler plant with fuelling with liquid fuels as the boiler fuelled with the biomass, than generally, for-fuel boxes are incorporated. Besides to the for-fuel box, it is obvious to incorporate a system for supplying and dosing of biomass. Boilers having medium- or higher powers, as the rule, are equipped with system for manipulation of fuels. The degree of usefulness of so designed boilers fuelled with biomass is within 55–96%, and newer boilers have higher usefulness degrees. Data on the total investments costs for the adopted bioenergetic installations and their comparison with classical installations fuelled with fuel oil and gas are shown in Table 4.

In order of enabling evaluation of these costs, the approximate costs of uprising of plants with similar capacities fired with natural gas or heating oil are shown. From the cited data it is possible to see that the costs for plants using the biomass in the EU are approximately two times higher, if compared with plants of the same power, fired by natural gas or with fuel oil. Investment costs for uprising of plants for biomass combustion in Vojvodina, if compared with the outlined data, are approximately for 40–50% lower,

Table 5
Calculation of investments for plant for combustion of straw.

Description	Units	Per unit (€)	Total (€)
Construction and installation of the hot water boiler of 400 kW	3	8638.1	25914.3
Construction and installation of the smoke chamber	3	990.5	2971.4
Construction and installation of the centrifugal ventilator	3	466.7	1400
Construction and installation of the self-supporting chimney	1	1828.6	1828.6
Total			32114.3

and this fact has to be taken into account for statement of total costs of combustion. The differences in the investment costs for such the plants is due to the fact that the plants for combustion of straw, made in our country, do not contain the complicated equipment neither for fuel manipulation, nor for treatment of the wasted smoke.

4.1. Costs of combustion of baled straw

In order of enabling comparisons of the technologies of pretreatment of straw, combustion costs are evaluated on the type plant. It was the plant for straw combustion having the power of 1.2 MW, with three installed boilers of 400 MW each, and with projected straw consumption of 1899 tons per year. For the mentioned plant and with the foreseen straw consumption, costs of combustion of straw collected by using of the two discussed collection modes were performed. Besides to that, costs for labor, consisting of two operators, are incalculated. The calculation of costs of salaries are performed by using the model applied for costs of permanently employed manpower, with the decreasing of net income for 30%, and earnings were incalculated for the period of 6 months. The mentioned decrease is justified by the fact that for these jobs workers possessing minimal qualifications in necessary, and that the heating period lasts about a half of the year. Calculation of the investments for plant for biomass combustion shows Table 5.

According to legal regulations, depreciation time for such plants lasts eight years, i.e. depreciation rate amounts to 12.5%. By rating of the lifetime of plants that are for longer period of time in the exploitation, it is possible to conclude that the so determined period seems to be quite short, i.e. that the real lifetime is being longer. Because of that, for the needs of calculation of costs, period of fifteen years was applied, corresponding to the depreciation rate of 6.7%; for coal firing plant, lifetime of 20 years was adopted, corresponding to the depreciation rate of 5%. It was adopted that the maintenance costs are 3.5% based on the value of a new plant, and that they for the whole lifetime are something higher than 50% of the furnishing value, what is in conformity with data obtained from manufacturers [7–9]. With estimation of costs for such one unit, the basic data referring to the plant and other essential variables have to be applied (Table 6).

Besides to that, costs for maintenance, earnings, interests, engagement of resources and assurance are projected. These costs for the discussed plant are calculated for a period of one year and they are shown in Table 7.

Table 6
Basic data on the plant for combustion of straw.

Description	Unit	Value
Depreciation base	€	32114.3
Depreciation period	Year	15
Depreciation rate	%	6.7
Interest rate	%	7.0

Table 7
Calculation of costs of exploitation of plant for combustion of straw.

Category of costs	Amount (€)	Structure (%)
Depreciation	2140.9	29.09
Maintenance	1124	15.27
Earnings	2968.7	40.34
Interests	1027.6	13.96
Assurance	97.9	1.33
Total	7359.3	100

Table 8
Costs of combustion of small rectangular bales.

Description	Unit	Sum
Total quantity of the burned straw	tons	1899
Combustion costs per ton	€/ton	3.87
Coefficient of utilization of fuel	%	65
Corrected costs of combustion per ton	€/ton	10.03

Table 9
Costs of combustion of roll-shaped bales.

Description	Unit	Value
Total quantity of the burned straw	tons	1899
Combustion costs	€/ton	3.87
Coefficient of utilization of fuel	%	65
Corrected costs of combustion per ton	€/ton	9.48

Comparability of costs of the energetic exploitation of straw, i.e. of so obtained energy, with energy obtained by combustion of an alternative fuel, in our case of coal, is not possible to apply without taking in account of the two kinds of corrections. Many analyses have not respected this circumstance and their results were in favor of combustion of straw. The unavoidable corrections refer to the correction with respect to the increased costs for exploitation of plant for straw combustion, and correction for the decreased degree of efficiency of the fuel usage. Correction for the increased costs of plant exploitation, i.e. of the firebox, is performed by comparing of the total costs for the plant for straw combustion and the parallel plant that uses coal as the fuel. Correction referring to the diminished degree of utilization of fuel is performed by the increasing of the combustion costs on account of the not utilized part. The degree of utilization of fuel was estimated to be 65%. Final comparability is made possible by calculation of costs for 10 MW of the obtained energy. The results of exploitation of the analyzed plant according to the outlined method are given separately for small rectangular- and for the roll-shaped bales [10–12]. Analyze of costs of combustion for small rectangular bales that include the loss that appears due to the incomplete utilization of fuel is shown in Table 8.

Owing to the difference in fuel prices, i.e. of the baled straw per ton, losses of fuel due to the incomplete utilization in the case of the roll-shaped bales is with respect to their value lower that that for small rectangular bales, so that costs of combustion of roll-shaped bales are given superlatively (Table 9).

Final comparability enables recalculation of costs per 10 MJ of the obtained energy. Results of exploitation of the analyzed plant in the case of using of small rectangular bales as a fuel are given in Table 10.

Table 10
Estimated energy price with combustion of small rectangular bales.

Description	Unit	Value
Straw price	€/ton	17.6
Costs of combustion (corrected)	€/ton	10.03
Total costs of energy production	€/ton	27.6
Energetic value of fuel	kJ/ton	124.8
Costs for production of 10 MJ of energy	€	21.1

Table 11
Estimated energy price with combustion of large roll-shaped bales.

Description	Unit	Value
Straw price	€/ton	16
Costs of combustion (corrected)	€/ton	9.5
Total costs of energy production	€/ton	25.5
Energetic value of fuel	kJ/ton	124.8
Costs for production of 10 MJ of energy	€	19.5

Results for the same plant, in the case of incineration of the roll-shaped bales are given in Table 11.

5. Conclusions

Costs for plants that apply biomass in the EU are approximately twice higher than costs for plants with the same power, fired with natural gas of with fuel oil. Costs of investments for the constructing of plants for combustion of biomass in Vojvodina are, with respect to the mentioned data, for 40–50% lower, so that this fact has to be taken into account at the evaluation of the combustion costs. Difference in the construction costs of such the very plants lies in the fact that the plants, constructed in Serbia, do have neither complicated devices for fuel manipulation, nor devices for treatment of smoke.

Definitive conclusions about the economic justification of the energetic exploitation of the stubble cereals straw can be made only by comparison of costs of so obtained energy with the costs of energy produced by conversion of classical fuels. Previous comparisons were based to the price of obtaining of the equivalent quantity of straw with the price of fuel oil or other classical energents. Such comparisons have leaded to the very positive estimations of economic effects of exploitation of straw, without taking into account the feasibility of the mentioned method. Namely, if straw and fuel oil were compared, hardly that one can conclude that these two fuels are interchangeable. According to the physical properties, straw is most similar to wood, but shortage of this resource and its preciousness exclude it from the comparative analysis, so that for comparison purposes coal must be used. The basic reason for applying of coal as an alternative energent is the circumstance that it represents very much used energent, its combustion technology resembles the technology of baled straw combustion and, at the same time, it has not any other application.

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